GEOTHERMAL INVESTIGATIONS
IN IDAHO

GEOTHERMAL RESOURCE ANALYSIS IN TWIN FALLS COUNTY, IDAHO

PART 2

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DISCLAIMER

GEOTHERMAL RESOURCE ANALYSIS IN TWIN FALLS COUNTY, IDAHO

PART II

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**GEOTHERMAL RESOURCE ANALYSIS
IN TWIN FALLS COUNTY, IDAHO, PART II**

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ABSTRACT

Thermal water is prevalent throughout central Twin Falls County. Most wells and springs that occur in the area produce thermal water from fractures in the Idavada Volcanics. However, in an area east of Hollister, thermal water issues from fractures in the Paleozoic rocks. In an attempt to explain the hydrothermal relationship between these two reservoir rocks, one composite model for the entire geothermal system in the area is proposed. As with other conceptual models of the system, available geologic, hydrologic, and geochemical data were used to develop the model.

The mountainous terrain to the south and southeast of the study area is thought to be the recharge area for the geothermal system. Natural discharge from the system occurs primarily through upward leakage to the overlying cold-water system. Where topographic and geologic conditions are favorable, thermal water issues at land surface as springs and seeps. Based on the relative positions of the presumed recharge and discharge areas of the system, a north- to northwest direction of flow is implied.

The chemistry of the thermal water appears to be strongly governed by the chemical composition of the rocks that it comes in contact with and the length of time that it is exposed to them. The shorter flow paths to the south appear to occur entirely within the Paleozoic rocks, according to the calcium bicarbonate chemistry of the thermal water. As the flow paths become progressively longer towards the north, the thermal waters apparently encounter the silicic volcanics during their ascent. The chemistries of the thermal waters gradually equilibrate to the new host rock conditions and lose their Paleozoic signatures as exposure time increases. Ultimately, the chemistry of the thermal water changes to a sodium bicarbonate type.

Significant declines have been observed in the potentiometric surface in areas where development of the thermal resource have been most concentrated. However, based on observed water-level trends, it appears that the current withdrawals from the system do not exceed the amount of recharge entering it. Apparently, the amount of upward leakage that naturally took place in these areas has been reduced by approximately the amount of discharge from wells.

INTRODUCTION

Although the thermal resource in central Twin Falls County (see Figure 1) has been extensively utilized, it has only recently been studied in detail. Street and DeTar (1987) and Lewis and Young (1989) developed conceptual models of the geothermal system, based primarily upon geologic, geophysical, and geochemical data. It is hoped that sufficient understanding of the system can be reached with these models so that future research can be better focused and future management decisions better applied.

The initial part of this study was completed by Street and DeTar in 1987, to provide baseline data on geology, long and short-term pressure and temperature fluctuations in the system, basic geochemistry of the thermal water, and to collect rock samples from the suspected reservoir rocks for future geochemical analysis. Upon completion of the first study phase, Street and DeTar provided several suggestions and recommendations for future study, which were incorporated into this part of the study. These included continued monitoring of pressures and temperatures in the geothermal system, additional water chemistry, and reservoir rock geochemistry.

After collecting some of the basic data for Part 2, Street left the Idaho Department of Water Resources (IDWR) before having the opportunity to interpret the data or to record her conclusions. As a result, the current authors are solely responsible for the interpretations made and conclusions drawn in this phase of the study.

Previous Work

Comprehensive summaries of previous work done in the region of the study area are included in Street and DeTar (1987), and in Lewis and Young (1989) and are not reiterated here. Street and DeTar (1987) focussed primarily on the geologic framework and monitoring of changes in head and pressure within the geothermal system, particularly in the vicinity of Banbury Hot Springs and the city of Twin Falls. Lewis and Young (1989) evaluated the volume, temperature, pressure, and water chemistry of the geothermal system and developed a preliminary conceptual model.

Well- and Spring-Numbering System

The well- and spring-numbering system used in this report is identical to the system that is used by the U. S. Geological Survey (USGS) in Idaho (see Figure 2). The system indicates the location of wells and springs within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section

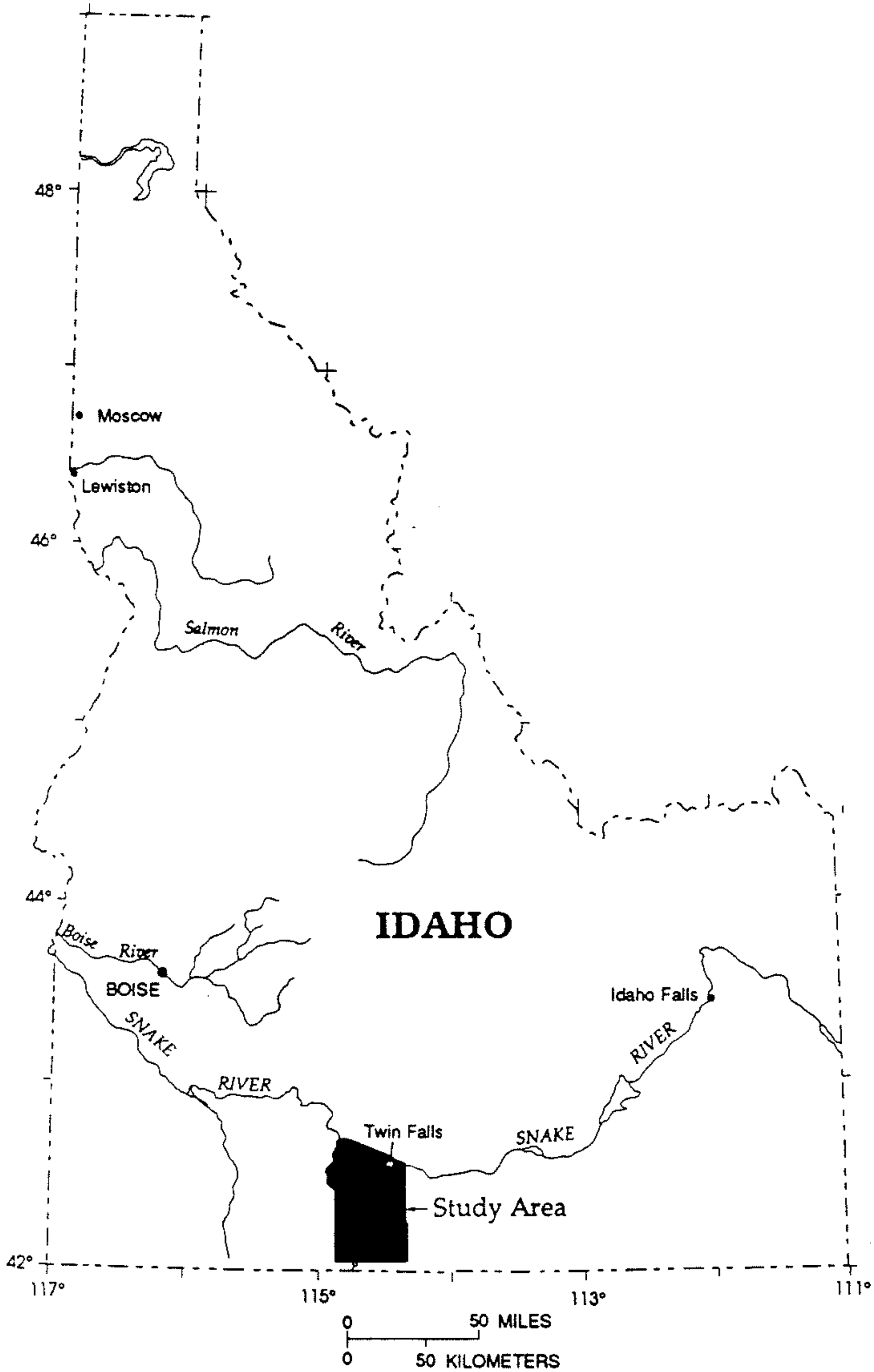


Figure 1.--Location of study area.

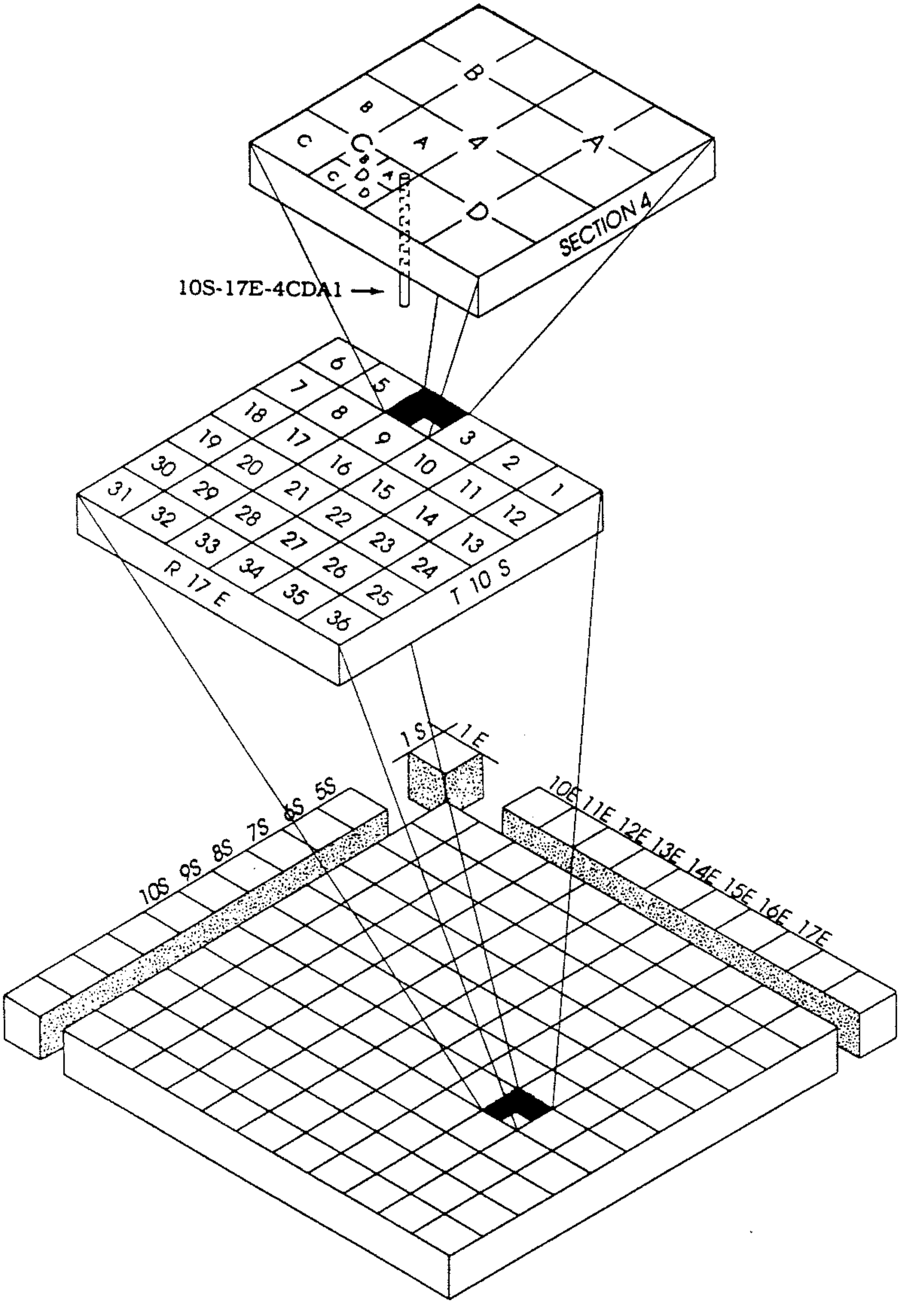


Figure 2.--Well- and spring-numbering system.

number, followed by three letters and a numeral, which indicate the ¼ section (160-acre tract), ¼-¼ section (40-acre tract), ¼-¼-¼ section (10-acre tract), and serial number of the well within the tract. Quarter sections are lettered A, B, C, and D in counterclockwise order from the northeast of each section. Within quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 10S-17E-04CDA1 is in the NE¼, SE¼, SW¼, sec. 4, T. 10 S., R. 17 E., and was the first well inventoried in that tract. Springs are designated by the letter "S" following the last numeral; for example 15S-14E-19CDD1S.

GEOLOGIC FRAMEWORK

Stratigraphy

Both Street and DeTar (1987) and Lewis and Young (1989) discussed the general geology of the area and provide a more detailed view than is necessary for this part of the report. An abbreviated description follows:

The oldest rocks in the area consist primarily of Paleozoic and Mesozoic marine sediments of limestone, dolomitic limestone, siltstone, quartzite and chert. They are exposed within the Cassia Mountains and in a small area southeast of Hollister, and are described in the driller's logs of two wells within the study area. In the Jarbidge Mountains to the southwest, sedimentary rocks are about 4,900 feet thick. North of the Cassia Mountains, these rocks are not encountered in wells as deep as 2500 feet, but probably do extend beneath the entire study area.

Overlying the sedimentary rocks are the Tertiary Idavada Volcanics. These rocks consist of rhyolitic welded ash-flow tuffs, with lesser amounts of rhyolitic lava and intercalated tuffaceous lacustrine sediments. They are exposed in the Cassia Mountains, the Snake River Canyon near Twin Falls and in the Salmon Falls Creek canyon along the western edge of the study area.

Lapping up on the Idavada Volcanics and related rhyolitic rocks are basalts of Tertiary to Quaternary age. The older basalts, collectively termed Banbury Basalt, are intercalated with minor stream and lake sediments. The younger basalts, of Pliocene to Pleistocene age, are part of the Glenns Ferry Formation of the Snake River Group. They tend to be much fresher-appearing and are much less altered than the older basalts.

Structure

The study area lies along the northern margin of the Basin and Range province. Considerable extension of the earth's crust has occurred in this region since the late Tertiary, and is responsible for creating the dominant structural fabric of the province. During this tectonically-active time, changes in the orientation of the principal stresses have occurred.

From at least 17 million years ago (Ma) to about 14 Ma, stress fields were primarily oriented in west-southwest to east-northeast directions in the region (Zoback, et al., 1981). The onset of this period brought about the development of the western Snake River Plain graben and related features. Within the study area, northwesterly-trending structures are apparent. One of the more obvious features that has been identified occupies a two-to-three mile wide band that traverses the study area from Berger Butte to Buhl, and was designated the Berger-Buhl Structure Zone (BBSZ) by Street and DeTar (1987). Because of its areal extent and deep-seated nature (evident by the volcanic activity along it), the BBSZ undoubtedly plays a significant role in governing the occurrence and movement of thermal waters in the area.

Following this major structural episode, a time-transgressive clock-wise rotation in principal stresses occurred, and by about 7 Ma, the present-day stress regime of west-northwest to east-southeast was in place in this region (Zoback, et al., 1981). This change in structural grain is apparent in the study area, although these latter features are secondary to the earlier west-northwest trending ones. The younger, north to northeastward trending structures commonly occur throughout the Cassia Mountains and generally offset and abut the older structures. This is apparent with the BBSZ, where its southeasterly extension may be truncated by a northeastward trending fault zone near Nat-Soo-Pah Warm Spring. Field investigation and aerial photography interpretation in the area support this conclusion.

The principal structures that occur within the study area, as described above, are shown in Plate 1 of Street and DeTar's (1987) report.

Geophysics

The only geophysical work that has been conducted in the area was accomplished by the USGS in 1982 and 1985, as part of the Regional Aquifer-System Analysis of the Snake River Plain (Bisdorf, 1987). The work consisted of electrical resistivity soundings that were preformed along four profile lines. Interpretations of these profiles generally indicated that three major units occur in the subsurface, based on differences in their apparent resistivities.

The upper unit, with apparent resistivities ranging from 100 to about 450 ohm-meters, was determined to be basalt with some intercalated sediments. The unit ranged in thickness from about 650 feet near the Snake River Canyon to about 1500 feet thick between Rogerson and Hollister.

The middle unit, with apparent resistivities ranging from 10 to less than 100 ohm-meters, has been at least tentatively correlated with the Idavada Volcanics, although the unit has not been drilled throughout its thickness to verify it's identity. The unit varies in thickness from about 3000 feet near Hollister to about 700 feet near the Snake River. The resistivity profiles also confirmed the existence of faults that were previously mapped at the surface. It is not apparent from the data whether or not the fault offsets extend to great depth, and would afford avenues for the movement of thermal water.

The lower unit, with apparent resistivities ranging from 100 to as much as 300 ohm-meters at increasing depths, cannot positively be identified, but is thought to be Paleozoic marine sediments. There is little resistivity contrast between the middle and lower units in the southern part of the study area at depth, perhaps indicating that thermal water migrating upward through both units from depth could be the cause (Lewis and Young, 1989).

HYDROLOGIC REGIME

Occurrence and Movement of Thermal Water

Thermal water is prevalent throughout the entire study area. Areas of known occurrence of the thermal resource are primarily in the northern portion of the study area (at and north of Buhl, Filer, and Twin Falls) and in the areas near Hollister and Rogerson. Most wells and springs that occur in the area produce thermal water from fractures in the Idavada Volcanics. However, in an area east of Hollister, thermal water issues from fractures in the Paleozoic rocks. Sixty-three thermal wells and three thermal spring sites have been inventoried in the study area. Their locations are shown on Figure 3.

The direction of movement of thermal water in the study area is largely unknown and can only be inferred based on the limited data available. In general, ground water moves from areas of recharge to areas of discharge. The mountainous terrain to the south and southeast of the study area is thought to be the recharge area for the geothermal system. Prior to development, natural discharge from the system issued from springs and seeps north of Buhl and east of Hollister. Based on the relative positions of the presumed recharge and discharge areas of the system, a north to northwest direction of flow is implied. Apparent hydraulic gradients in the study area range from 0.009 to 0.013 (Lewis and Young, 1989). A generalized configuration of the potentiometric surface for the geothermal system is shown in Figure 4.

Temperatures of the thermal water range from 30° to 72°C (86° to 162°F), with the highest recorded temperatures observed in the area north of Buhl. Water temperatures from some wells that occur

CENTRAL TWIN FALLS COUNTY

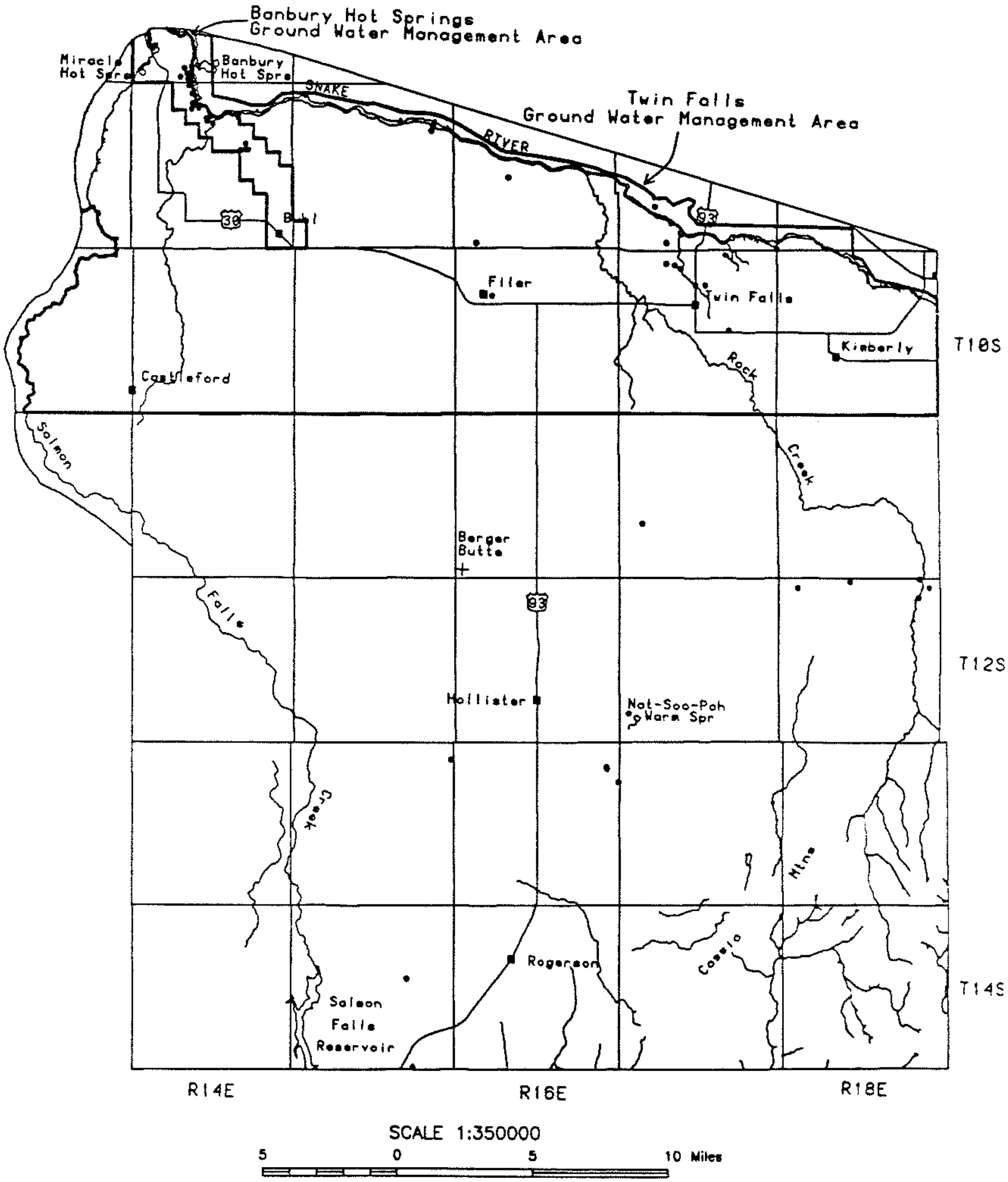


Figure 3. MAP SHOWING LOCATIONS OF THERMAL WELLS AND SPRINGS

CENTRAL TWIN FALLS COUNTY

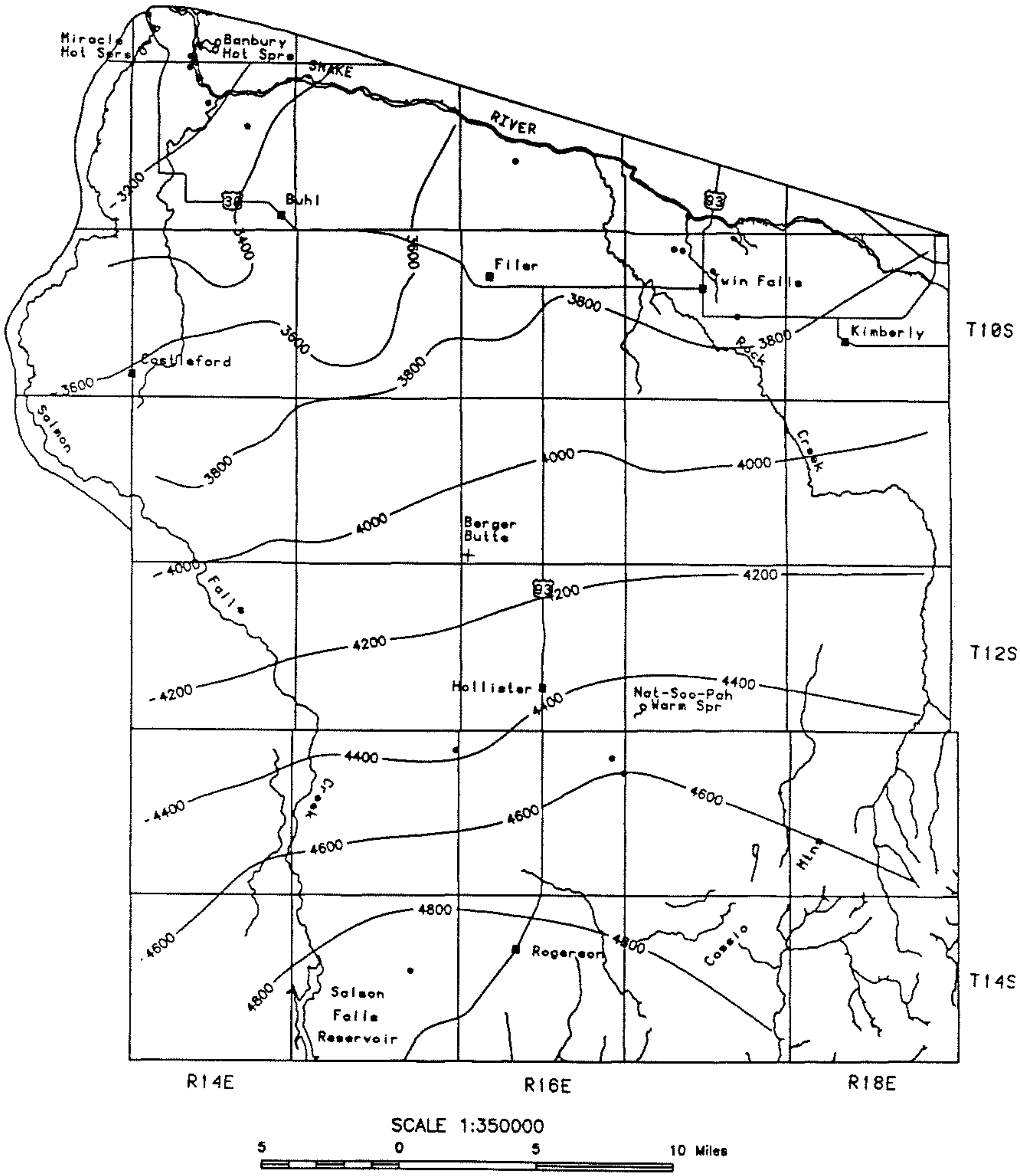


Figure 4. GENERALIZED POTENTIOMETRIC SURFACE MAP, SPRING 1988

between areas of known thermal occurrence suggest that mixing of cold and thermal waters may be taking place in these areas (Lewis and Young, 1989). Water temperatures in these wells show values several degrees above the mean ambient air temperature of 10°C (50°F).

Temperature Profiles/Geothermal Gradients

Temperature profiles were run in three wells distributed throughout the study area; wells 10S-18E-01DDD1, 13S-16E-12DAA1, and 09S-14E-21ABA1. Two of the wells produced results similar to those reported by Brott et al (1976); the third produced results related to well construction that allowed considerable mixing of thermal and non-thermal waters.

Temperature profile graphs for the three wells are illustrated in Figures 5(a), (b), and (c). Well 10S-18E-01DDD1 (Fig. 5a), about 1950 feet (640 m.) deep, penetrates through the overlying Snake River basalt at about 775 feet (254 m.) and remains in the Tertiary silicic volcanics to total depth. The borehole is open to the formation from about 1400 feet (459 m.) to total depth. Excursions of the temperature-depth trace from the general trend line between about 230 and 990 feet (75 and 325 m.) in Figure 5(a) is somewhat inexplicable, since the well is cased throughout this zone, but may be the result of both warmer and cooler bodies of water outside the casing. Where the well is open to the formation between about 990 and 1675 feet (325 and 550 m.), the trend is very close to what appears to be the average geothermal gradient of about 64°C./Km. in the borehole.

Well 09S-14E-21ABA1 (Fig. 5b), reported by the owner to have been deepened to about 625 feet (205 m.), shows some rather radical shifts in slope in the temperature profile, particularly between 425-520 feet (140-170 m.). The well log available is for the original well before deepening, and shows that the well penetrates black basalt which is probably Tertiary Banbury basalt to a depth of about 183 feet (60 m.) before penetrating brown and gray-green clay from 183-316 feet (60-104 m.). Casing extended from land surface to only 55 feet (18 m.) in depth in the original hole, but no information is available on how this well was cased once it was deepened. In the section of the hole above 425 feet (140 m.), the geothermal gradient was about 29°C./Km. From 425-518 feet (140-170 m.) the gradient was about 396°C./Km., indicating perhaps a significant amount of interaquifer flow and/or mixing with overlying colder water. Below 518 feet (170 m.) to total depth, the well was almost isothermal, indicating some uphole flow of water. Without better information on construction and operation of this well, geothermal gradient data cannot be interpreted with confidence.

Well 13S-16E-12DAA1 (Fig. 5c), about 825 feet (270 m.) deep, penetrates what appears to be exclusively Paleozoic sedimentary

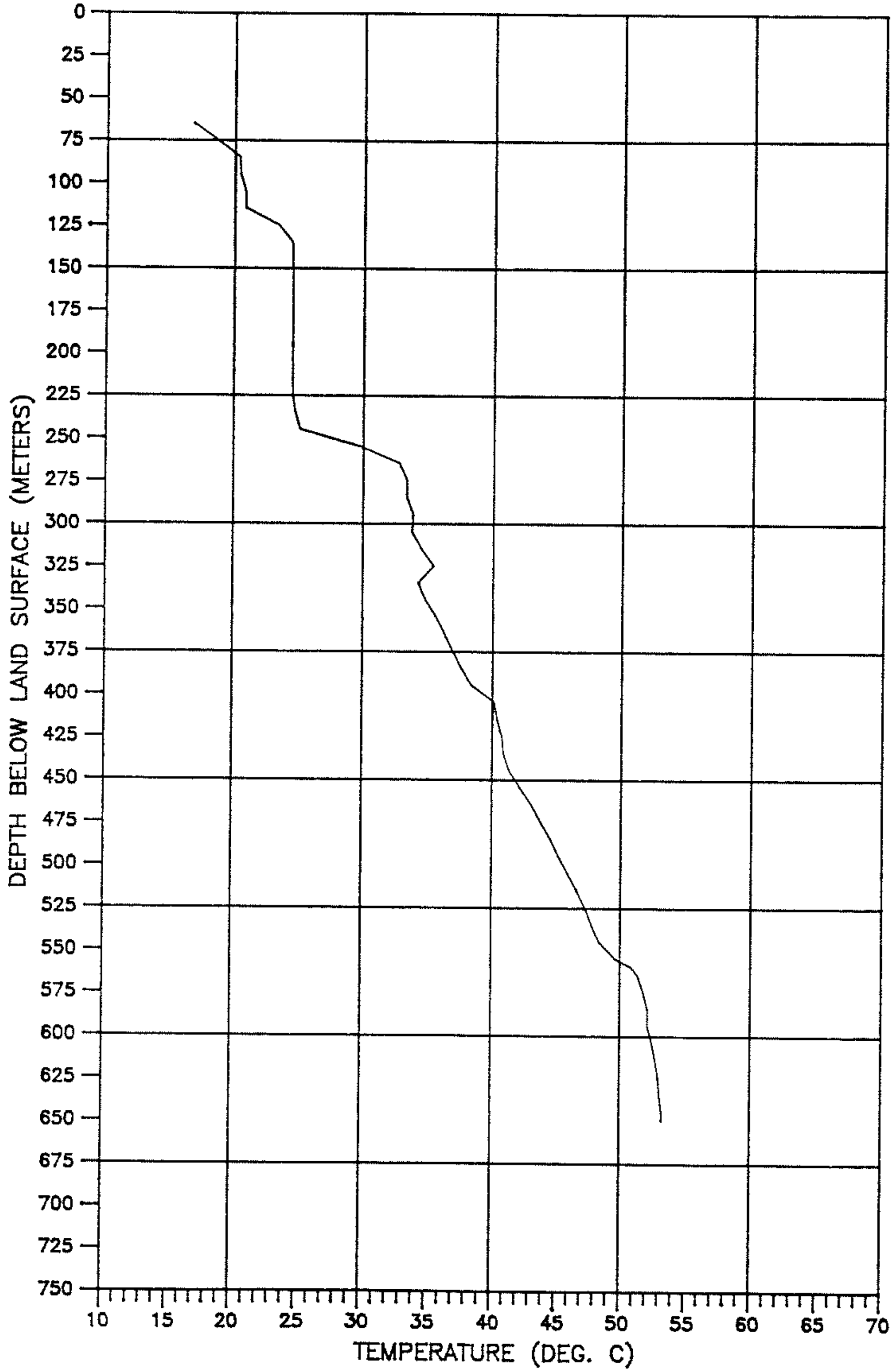


FIG. 5(a) Temperature Profile of Well 10S-18E-01DDD1

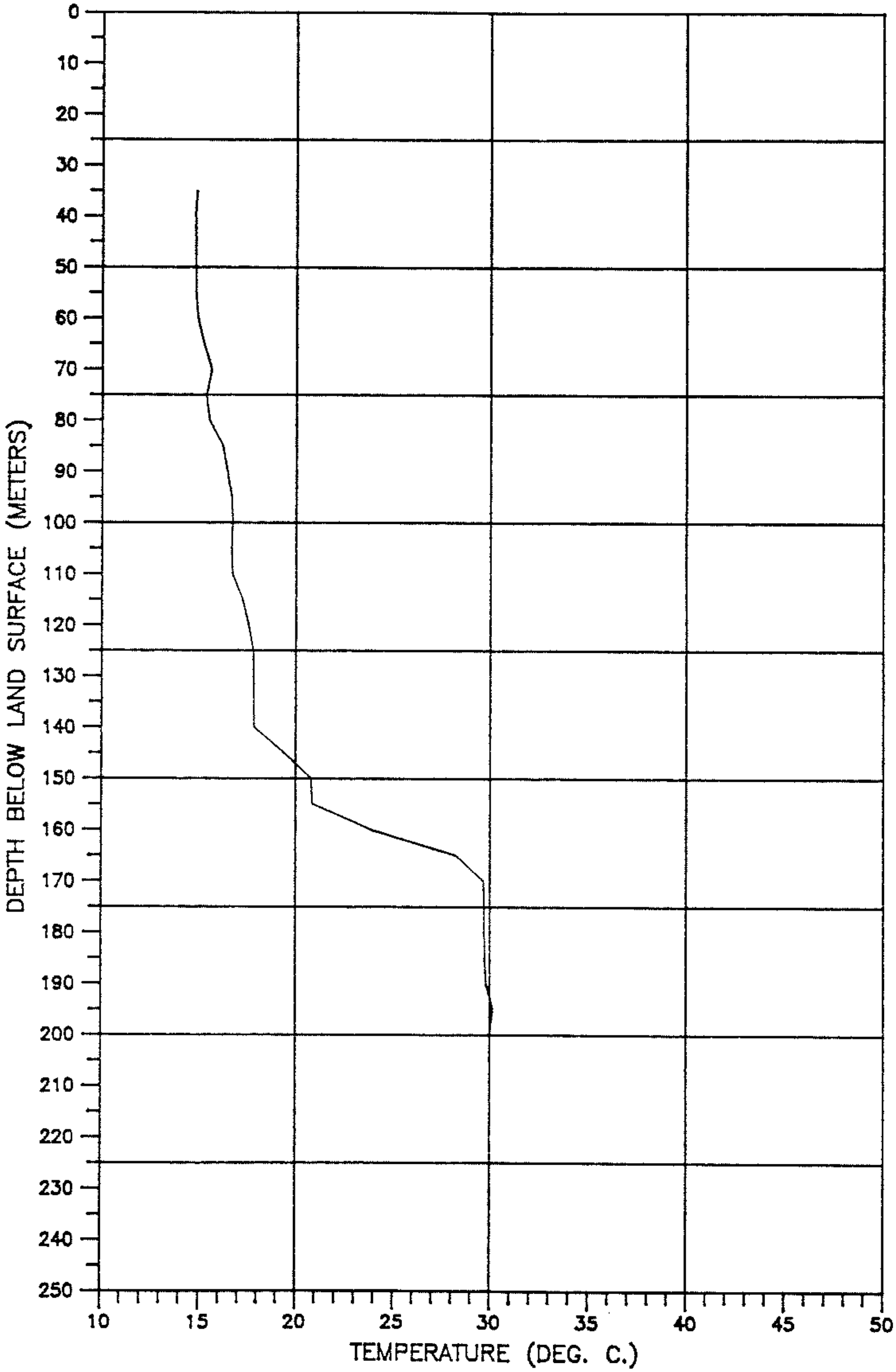


Figure 5(b) Temperature Profile of Well 9S-14E-21ABA1

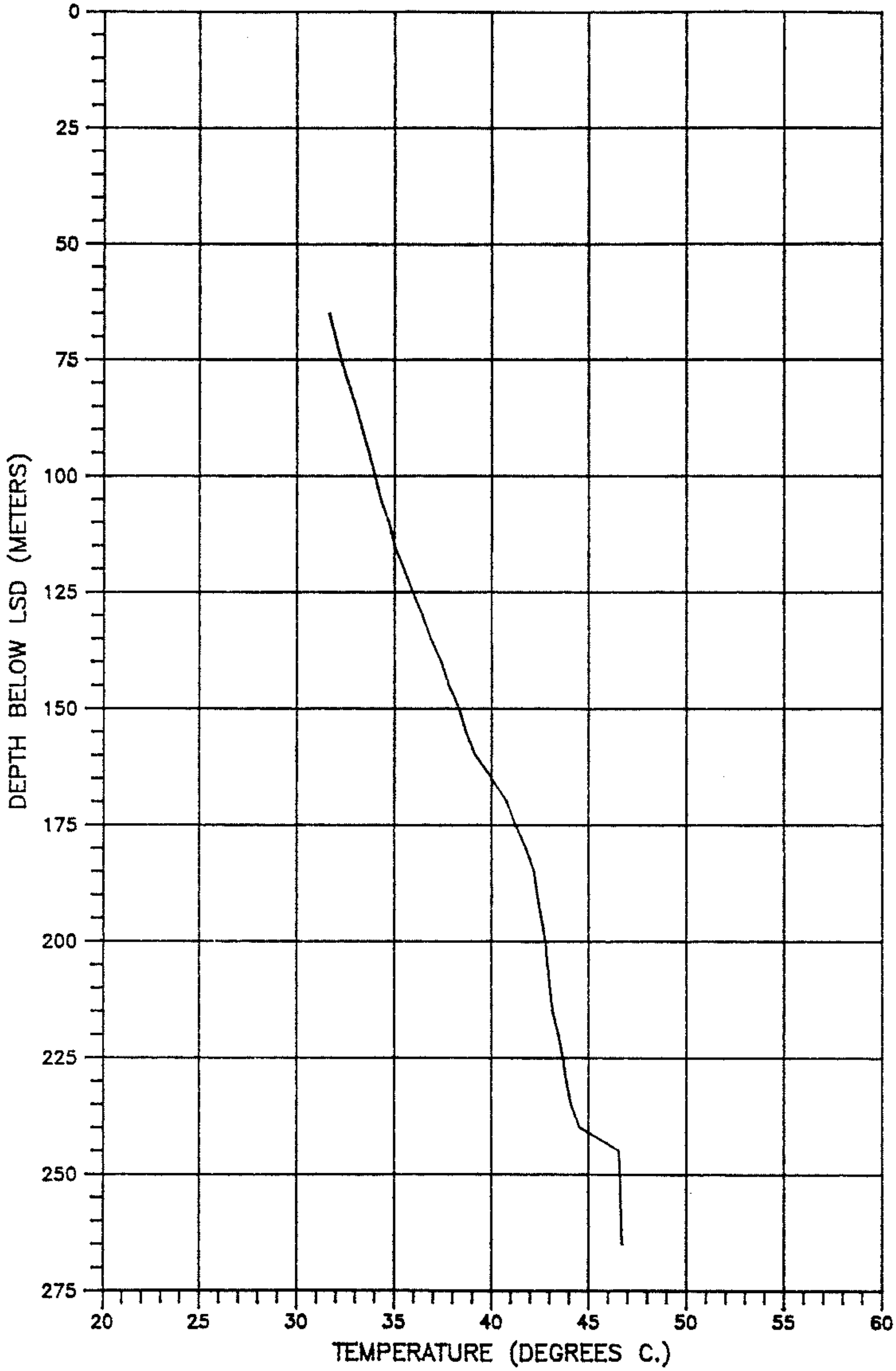


Figure 5(c) Temperature Profile of Well 13S-16E-12DAA1

Table 1(a) Temperature-Depth Log of Well 10S-18E-01DDD1

Depth (Meters)	Depth (Feet)	Temperature Deg. C	Deg. F	Geothermal Gradient Deg C/Km	Deg F/100 Ft
65	198	16.71	62.07		
75	229	18.55	65.39	184	10.9
85	259	20.35	68.63	180	10.6
95	290	20.4	68.72	5	0.3
105	320	20.82	69.47	42	2.5
115	351	20.86	69.54	4	0.2
125	381	23.41	74.13	255	15.1
135	411	24.47	76.04	106	6.3
145	442	24.5	76.1	3	0.2
155	472	24.53	76.15	3	0.2
165	503	24.53	76.15	0	0.0
175	533	24.53	76.15	0	0.0
185	564	24.53	76.15	0	0.0
195	594	24.53	76.15	0	0.0
205	625	24.53	76.15	0	0.0
215	655	24.54	76.17	1	0.1
225	686	24.55	76.19	1	0.1
235	716	24.75	76.55	20	1.2
245	747	25.12	77.21	37	2.2
255	777	29.73	85.51	461	27.2
265	808	32.8	91.04	307	18.1
275	838	33.37	92.06	57	3.4
285	869	33.36	92.04	-1	-0.1
295	899	33.87	92.96	51	3.0
305	930	33.74	92.73	-13	-0.8
315	960	34.49	94.08	75	4.4
325	991	35.42	95.75	93	5.5
335	1021	34.23	93.61	-119	-7.0
345	1052	34.81	94.65	58	3.4
355	1082	35.63	96.13	82	4.8
365	1113	36.28	97.30	65	3.8
375	1143	36.9	98.42	62	3.7
385	1173	37.58	99.64	68	4.0
395	1204	38.34	101.0	76	4.5
405	1234	40.17	104.3	183	10.8
415	1265	40.38	104.6	21	1.2
425	1295	40.78	105.4	40	2.4
435	1326	40.9	105.6	12	0.7
445	1356	41.53	106.7	63	3.7
455	1387	42.21	107.9	68	4.0
465	1417	43.12	109.6	91	5.4
475	1448	43.83	110.8	71	4.2
485	1478	44.59	112.2	76	4.5
495	1509	45.21	113.3	62	3.7
505	1539	45.94	114.6	73	4.3
515	1570	46.63	115.9	69	4.1
525	1600	47.27	117.0	64	3.8
535	1631	47.8	118.0	53	3.1
545	1661	48.38	119.0	58	3.4
555	1692	49.65	121.3	127	7.5
560	1707	50.87	123.5	244	14.4
565	1722	51.37	124.4	100	5.9
575	1753	51.81	125.2	44	2.6
585	1783	52.16	125.8	35	2.1
595	1814	52.14	125.8	-2	-0.1

Table 1(a) Temperature-Depth Log of Well 10S-18E-01DDD1 (Continued)

Depth (Meters)	Depth (Feet)	Temperature Deg. C	Temperature Deg. F	Geothermal Gradient Deg C/Km	Geothermal Gradient Deg F/100 Ft
605	1844	52.5	126.5	36	2
615	1875	52.77	126.9	27	1.6
625	1905	53	127.4	23	1.4
635	1935	53.09	127.5	9	0.5
645	1966	53.26	127.8	17	1.0
650	1981	53.26	127.8	0	0.0

Table 1(b) Temperature-Depth Log of Well 09S-14E-21ABA1

Depth (Meters)	Depth (Feet)	Temperature Deg. C	Temperature Deg. F	Geothermal Gradient Deg C/Km	Geothermal Gradient Deg F/100 Ft
35	107	14.79	58.62		
40	122	14.73	58.51	-12	-0.7
45	137	14.74	58.53	2	0.1
50	152	14.76	58.56	4	0.2
55	168	14.77	58.58	2	0.1
60	183	14.88	58.78	22	1.3
65	198	15.2	59.36	64	3.8
70	213	15.6	60.08	80	4.7
75	229	15.31	59.55	-58	-3.4
80	244	15.49	59.88	36	2.1
85	259	16.18	61.12	138	8.1
90	274	16.41	61.53	46	2.7
95	290	16.64	61.95	46	2.7
100	305	16.7	62.06	12	0.7
105	320	16.62	61.91	-16	-0.9
110	335	16.69	62.04	14	0.8
115	351	17.22	62.99	106	6.3
120	366	17.54	63.57	64	3.8
125	381	17.78	64.00	48	2.8
130	396	17.81	64.05	6	0.4
135	411	17.82	64.07	2	0.1
140	427	17.83	64.09	2	0.1
145	442	19.41	66.93	316	18.7
150	457	20.81	69.45	280	16.5
155	472	20.89	69.60	16	0.9
160	488	23.89	75.00	600	35.4
165	503	28.27	82.88	876	51.7
170	518	29.7	85.46	286	16.9
175	533	29.73	85.51	6	0.4
180	549	29.74	85.53	2	0.1
185	564	29.76	85.56	4	0.2
190	579	29.83	85.69	14	0.8
195	594	30.19	86.34	72	4.3
200	610	29.98	85.96	-42	-2.5
205	625	29.98	85.96	0	0.0

Table 1(c) Temperature-Depth Log of Well 13S-16E-12DAA1

Depth (Meters)	Depth (Feet)	Temperature Deg. C	Temperature Deg. F	Geothermal Gradient Deg C/Km	Geothermal Gradient Deg F/100 Ft
65	198	31.66	88.98		
70	213	31.96	89.52	60	3.5
75	229	32.26	90.06	60	3.5
80	244	32.64	90.75	76	4.5
85	259	33.02	91.43	76	4.5
90	274	33.35	92.03	66	3.9
95	290	33.71	92.67	72	4.3
100	305	34.01	93.21	60	3.5
105	320	34.3	93.74	58	3.4
110	335	34.72	94.49	84	5.0
115	351	35	95	56	3.3
120	366	35.49	95.88	98	5.8
125	381	35.93	96.67	88	5.2
130	396	36.45	97.61	104	6.1
135	411	36.86	98.34	82	4.8
140	427	37.39	99.30	106	6.3
145	442	37.79	100.0	80	4.7
150	457	38.31	100.9	104	6.1
155	472	38.67	101.6	72	4.3
160	488	39.14	102.4	94	5.6
165	503	40	104	172	10.2
170	518	40.79	105.4	158	9.3
175	533	41.25	106.2	92	5.4
180	549	41.79	107.2	108	6.4
185	564	42.21	107.9	84	5.0
190	579	42.37	108.2	32	1.9
195	594	42.59	108.6	44	2.6
200	610	42.78	109.0	38	2.2
205	625	42.9	109.2	24	1.4
210	640	43.03	109.4	26	1.5
215	655	43.15	109.6	24	1.4
220	671	43.45	110.2	60	3.5
225	686	43.69	110.6	48	2.8
230	701	43.86	110.9	34	2.0
235	716	44.1	111.3	48	2.8
240	732	44.56	112.2	92	5.4
245	747	46.54	115.7	396	23.4
250	762	46.6	115.8	12	0.7
255	777	46.63	115.9	6	0.4
260	792	46.66	115.9	6	0.4
265	808	46.7	116.0	8	0.5

rocks exposed on the westernmost flanks of the Cassia Mountains. The borehole is cased to 302 feet (99 m.) and is then open-hole to total depth. Fifteen feet of drill tools still stuck in the bottom of the hole prevented temperature logging to full depth; however, as can be seen in Figure 5(c), the trend near total depth was to isothermal conditions. The average geothermal gradient in the borehole was about 75°C./Km.

Published temperature profiles and geothermal gradients for the Snake River Plain and marginal areas (Brott, et al. 1976) indicate a range in geothermal gradient of from 33-186°C./Km. for the southern part of the Snake River Plain and the western portion of this study area. The two geothermal gradient determinations accomplished for this study are obviously well within the limits of Brott et al. data, but lie above the approximate mean value of 55±5°C./Km. for the general area.

Effects of Development on Artesian Head

Significant declines have been observed in the potentiometric surface in areas where development of the thermal resource has been most concentrated. Initially, these areas of development were mainly centered around sites of natural discharge from the geothermal system where warm springs and seeps occurred. They include Banbury and Miracle Hot Springs north of Buhl and Nat-Soo-Pah Warm Spring east of Hollister. In the mid-1930's, thermal water was also discovered in the Twin Falls area while drilling a deep well for the city (Well 10S-17E-14CCD1). Later, in the early 1980's, exploratory drilling encountered a thermal resource in an area southwest of Rogerson.

In order to monitor what changes were occurring in the geothermal system due to the effects of development, artesian head was measured periodically in sixteen thermal wells in the study area. Nine of the wells were monitored by the IDWR, the remainder by the USGS. Water temperatures were also measured in eight of the IDWR observation wells. Temperatures seem to have remained relatively constant since monitoring began in the fall of 1983. However, short-term variations of few degrees Celsius do occur and are probably the result of seasonal changes in withdrawal.

General data regarding these wells and others mentioned in this report are listed in Table 2 and their locations are shown in Figure 6. Water-level hydrographs of eight of these wells are presented in Figures 7 - 10. Discussions regarding the effects of development in the areas previously mentioned are covered separately in the sections that follow. Street and DeTar (1987) also present detailed descriptions of the short-term fluctuations in artesian head that were observed in the IDWR observation wells in the area north of Buhl and Twin Falls.

Table 2. Records of selected wells and springs

Elevation: Estimated from USGS topographic maps and field surveys, in feet (datum is National Geodetic Vertical Datum of 1929).
Well Depth: Reported, in feet below land surface.
Well Opening: Reported, in feet below land surface.

Temperature: Measured, in degrees C / F.
Use of Water: H - Domestic, I - Irrigation, Q - Aquaculture, R - Recreation, S - Stock, U - Unused, V - Space Heating, Z - Other.

Well Number	Elevation of Land Surface	Well Depth	Depth to First Well Opening	Mean Water Temperature	Use of Water	Date of Well Completion
08S-14E-30ACA1	2898	760	301	65.8/150.4	H/V	11/16/79
08S-14E-30ACD3	2897	--	--	--	H/V	--
08S-14E-30DAD1	2900	700	501	62.0/143.6	V	2/ 1/78
08S-14E-30DBA1	2896	450	90	69.0/156.2	V	4/24/79
08S-14E-33CCA1	2908	510	210	44.3/111.8	V/I	3/ 1/75
09S-14E-04BBD1	2959	700	215	40.7/105.3	H/I	4/17/79
09S-14E-09ADC1	2996	850	380	31.8/89.2	Q/V	4/ 4/74
09S-14E-14BDB1	3146	906	346	33.3/91.9	I/V	8/11/80
09S-14E-21ABA1	3240	625	--	--	H/Z	2/10/88
09S-15E-12CCA1	3064	1430	1419	44.3/111.8	I/V	4/27/81
09S-15E-13BBD1	3442	610	--	46.0/114.8	H	--
09S-16E-20ADD1	3487	1247	735	30.5/86.9	U	8/31/84
09S-17E-29ACD1	3150	730	220	42.0/107.6	Q/U	12/10/70
09S-17E-33BBC1	3170	750	592	39.0/102.2	V/Z	12/27/81
10S-16E-08CAB1	3762	--	--	--	Z	--
10S-17E-04CDA1	3668	2220	1191	36.5/97.7	V/Q	11/21/79
10S-17E-05DAA1	3650	1450	1200	32.8/91.0	V/U	8/10/83
10S-17E-14CCD1	3788	1154	575	30.5/86.9	I	4/ 1/34
10S-18E-01DDD1	3955	1950	1460	--	H/R	6/ 1/85
12S-17E-31BAB2	4542	--	--	--	R	--
12S-18E-01BBA1	4172	755	--	38.0/100.4	I	1/ 1/05
12S-18E-24BBD1	4340	570	67	26.0/78.8	H	11/10/75
12S-18E-36BBA1	4460	400	--	25.5/77.9	H	1/ 1/30
13S-15E-01DAD1	4569	2255	1000	35.5/95.9	--	1/18/81
13S-16E-12DAA1	4742	825	302	36.5/97.7	I/U	10/ 7/68
14S-15E-14CBD1	4930	2525	1180	32.0/89.6	I	8/ 6/82
15S-14E-19CDD1S	7100	--	--	7.0/44.6	S	--

CENTRAL TWIN FALLS COUNTY

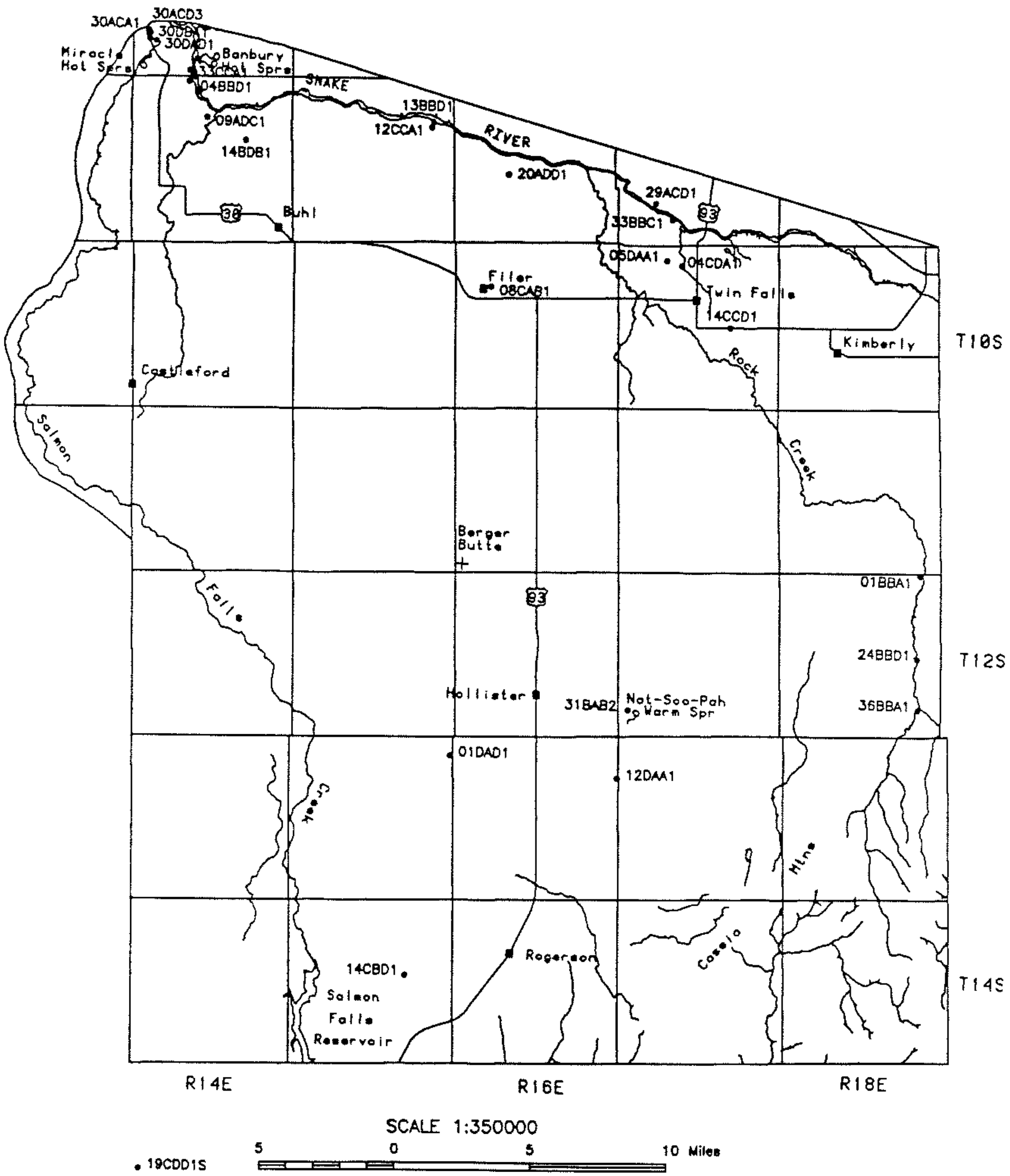


Figure 6. MAP SHOWING LOCATIONS OF SELECTED WELLS AND SPRINGS

North of Buhl

Most of the development in the area north of Buhl began in the early 1970's and was initially centered near Banbury and Miracle hot springs area. Currently, at least 35 thermal wells occur in the area. According to the driller's logs, well depths range from 210 to 1100 ft. The highest water temperature recorded in the area is 72.0 °C (161.6 °F).

The earliest recorded measurements of artesian head in this area were made in well 08S-14E-30DAD1 in the summer of 1978. At this time the elevation of the potentiometric surface was 3229 ft above mean sea level (MSL). However, a year later, it was at 3060 ft above MSL (a decline of about 170 ft). Measurements at this well offer the only documented evidence of what changes occurred in head locally during initial development. In 1979, total annual discharge from the local system was estimated at about 10,300 acre-ft (Lewis and Young, 1982).

As development gradually expanded in the area, the local potentiometric surface continued to decline. Figures 7 and 8 contain hydrographs of wells 08S-14E-30ACA1, 09S-14E-04BBD1, 09S-14E-09ADC1, and 09S-14E-14BDB1, that illustrate the effects of increased use on artesian heads in the area. From 1979 to 1983, declines in artesian head in the area ranged from 45 to 54 ft. In April 1983, the area was declared a Ground Water Management Area by IDWR and closed to new applications for development. Although the rate of decline slowed considerably, heads continued to drop as previously approved development continued to expand. In December 1985, a moratorium was placed on current development. Within a year, water levels stabilized, except for seasonal fluctuations.

In 1986, Street and DeTar (1987) estimated total discharge in the area at about 19,300 acre-ft annually (almost a two-fold increase in use over the seven-year period). Current withdrawal in the area has not changed appreciably from Street and DeTar's amount, since their estimate was made after the moratorium was implemented. The observed water-level trends in the area support this conclusion.

Twin Falls

After the completion of the city's well in the mid-1930's, development of thermal resource in the Twin Falls area did not resume until the early 1970's when well 09S-17E-29ACD1 was drilled in the Snake River Canyon. Several years passed, however, before the main thrust of development took place and most of the thermal wells were completed in the area. By the late 1980's, the USGS had inventoried 13 thermal wells in the immediate area. According to the drillers' logs, well depths range from 610 to 2220 ft. The highest water temperature recorded in the area is 42.0 °C (107.6 °F).

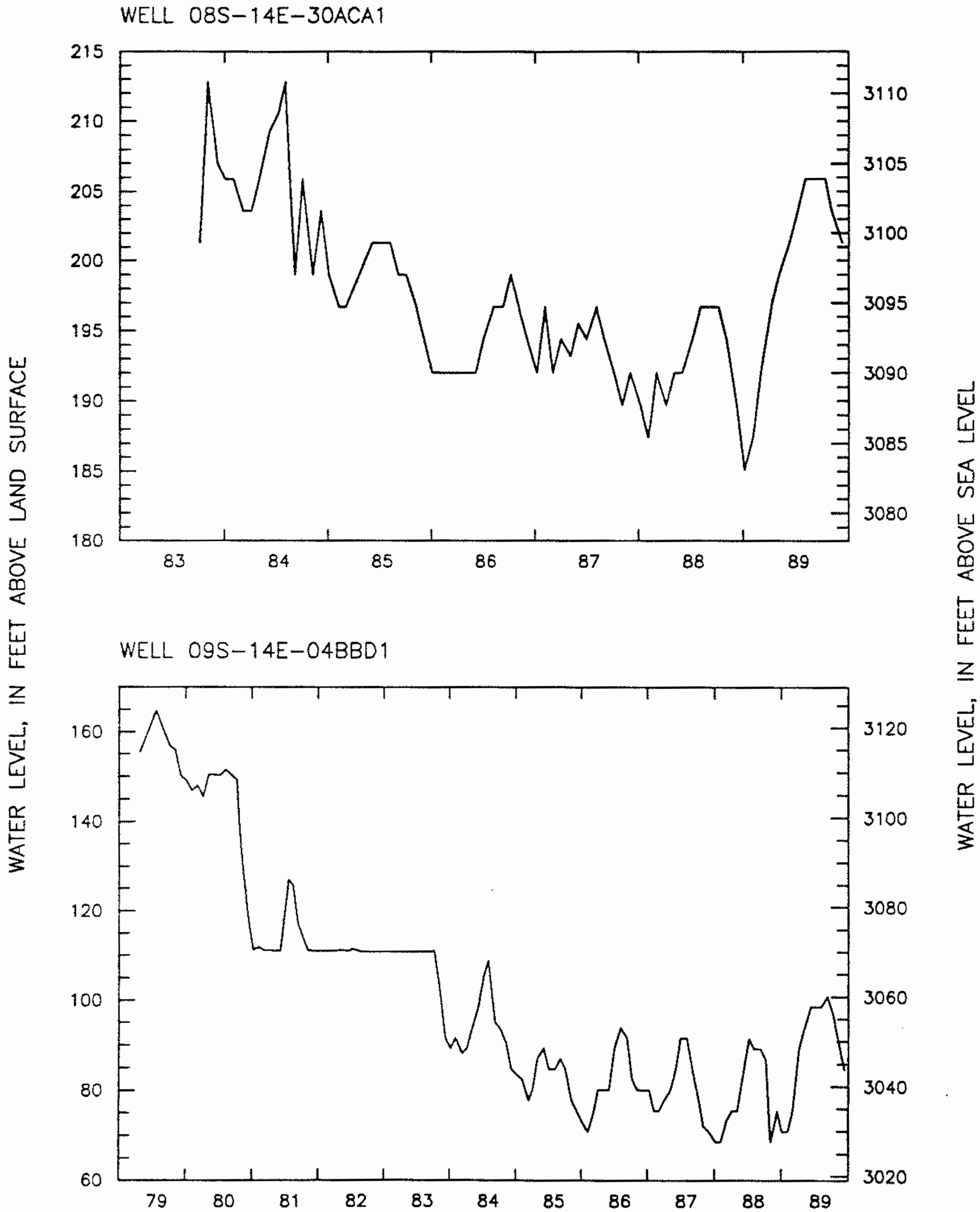


Figure 7. HYDROGRAPHS OF WELLS: 08S-14E-30ACA1 AND 09S-14E-04BBD1

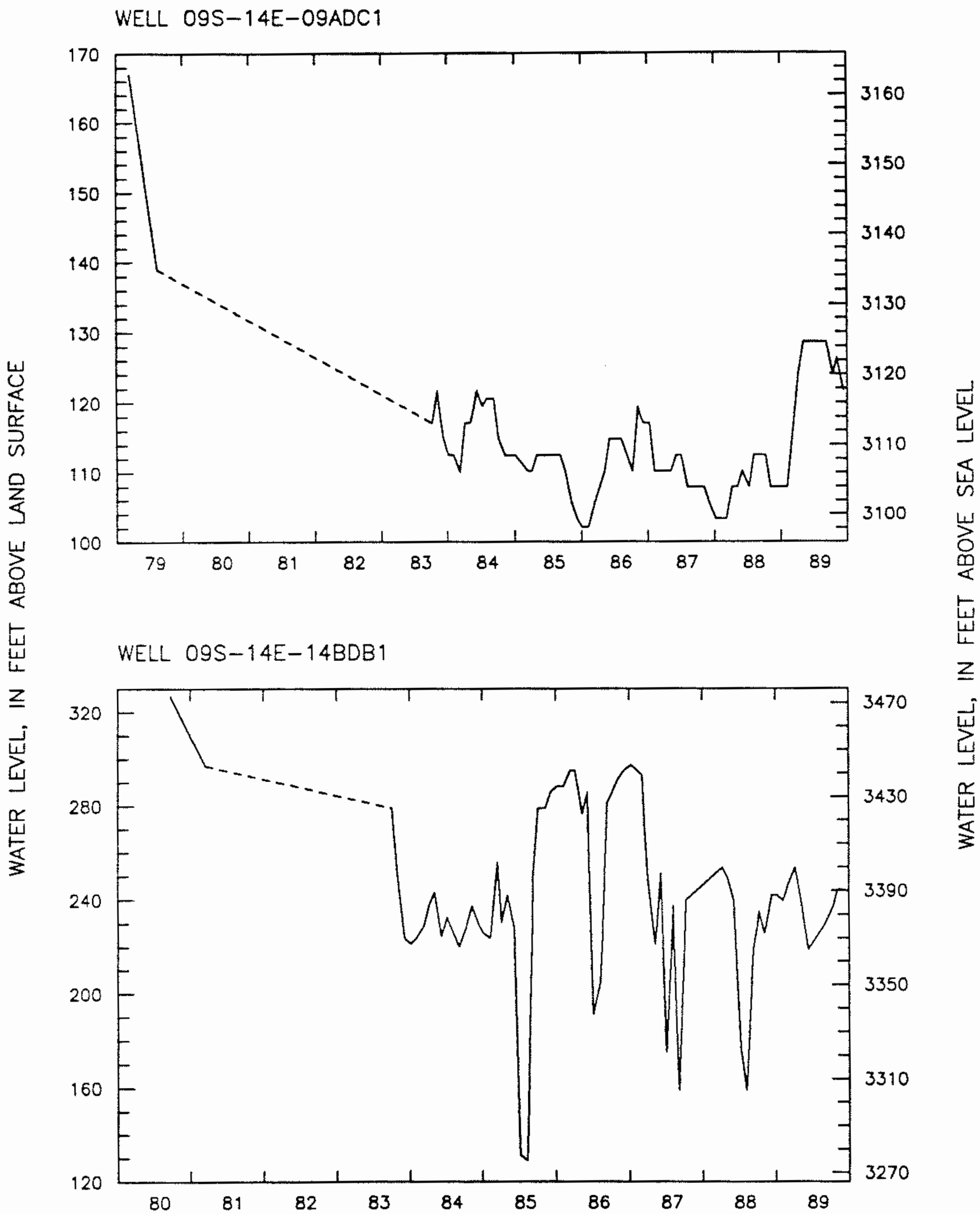


Figure 8. HYDROGRAPHS OF WELLS: 09S-14E-09ADC1 AND 09S-14E-14BDB1

Artesian head has been measured periodically in seven thermal wells in the immediate area. Hydrographs of two of these wells (09S-16E-20ADD1 and 10S-17E-05DAA1) are shown in Figure 9. Both show similar trends which reflect changes in local development. When well 09S-17E-33BBC1 was initially allowed to flow in September 1984, the potentiometric surface dropped dramatically, as is depicted on the hydrographs. The decline in artesian head at one of the observation wells was greater than 30 ft.

In order to reduce further declines in the geothermal system locally, the area was declared a Ground Water Management Area and was closed to new applications for development in January 1984. In 1986, total discharge in the immediate area was estimated at about 4,400 acre-ft annually (Street and DeTar, 1987). Because of concern over the effects of continued expansion of approved permits, a five-year moratorium was placed on development of the thermal resource in the vicinity of Twin Falls in July 1987.

Due to the rehabilitation of well 09S-17E-29ACD1 in the summer of 1986 and its subsequent shut-in the following spring, the local potentiometric surface rose substantially. Each of these events are clearly shown on the two hydrographs. Total rise in head at one of the observation wells was as much as 22 ft following the changes at this well. The rapid and significant response in head that has been observed from changes in development clearly shows the highly confined nature and relatively low permeability of the geothermal reservoir.

Current total discharge in the area is about 4,400 acre-ft/yr, and has not changed significantly since Street and DeTar's estimate was made in 1986. This is due to the fact that although development did continue throughout the period between the time their estimate was made and the moratorium was implemented, the amount of additional use that took place was in large part, if not completely, offset by the cessation in discharge at well 09S-17E-29ACD1. The observed water-level trends in the area support this conclusion.

East of Hollister

Development of the thermal resource began at a much earlier date in the area east of Hollister. In the early 1910's, shallow irrigation wells were drilled in the vicinity of Nat-Soo-Pah spring. Because of the age of the wells, driller's logs are not available for them. However, based on their proximity to the springs they were probably completed in the Paleozoic rocks. Since this time, development in the immediate area has expanded very little. Currently, about seven thermal wells occur in the immediate area. According to a review of water rights, average annual discharge in the area is estimated at 2000 acre-ft. Maximum temperature of the resource in the area has been recorded at 37.0 °C (98.6 °F).

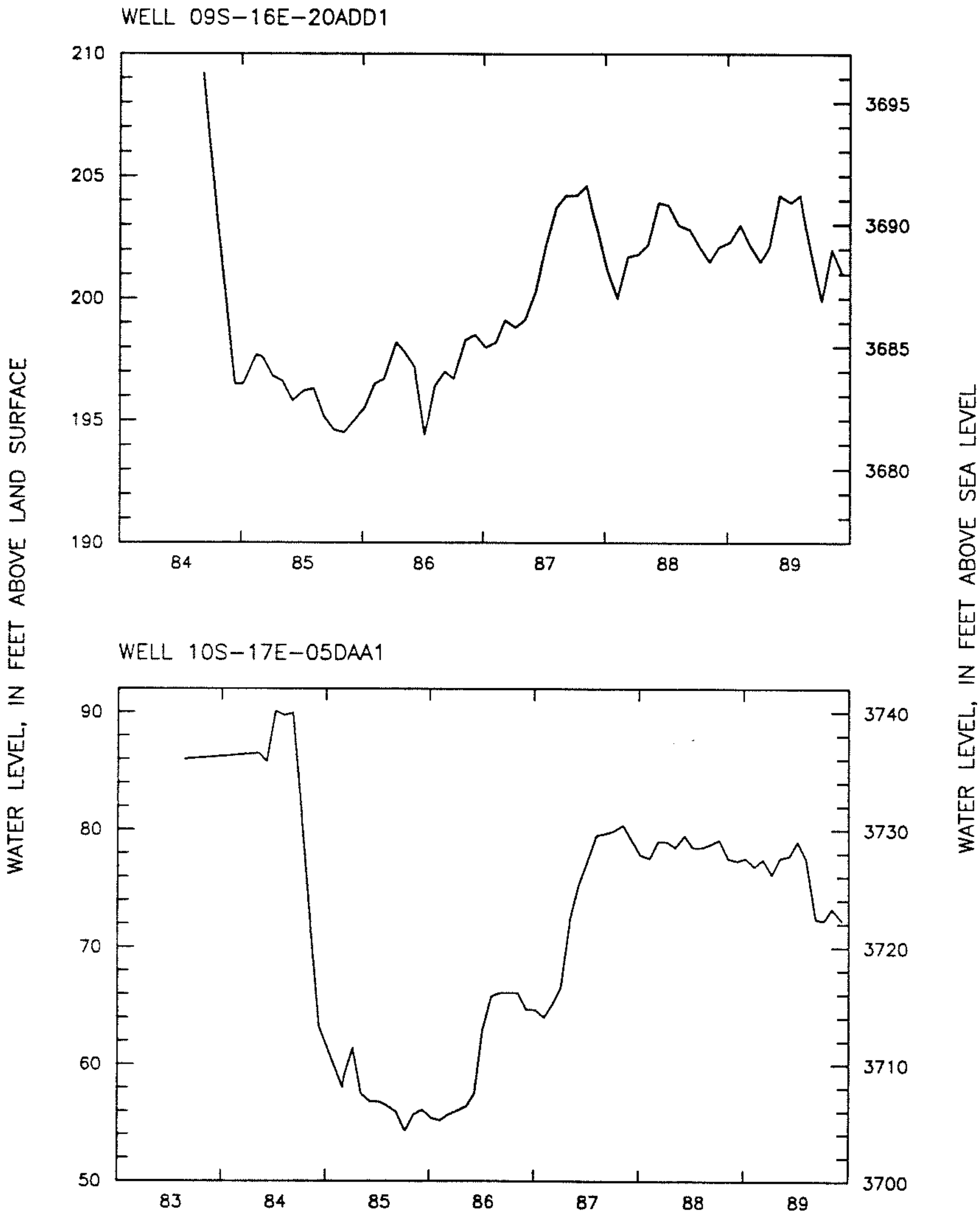


Figure 9. HYDROGRAPHS OF WELLS: 09S-16E-20ADD1 AND 10S-17E-05DAA1

The earliest recorded measurements of artesian head in this area were made in well 13S-16E-12DAA1 in the spring of 1979. However, it wasn't until Lewis and Young's study in 1988 that head in the well was measured on a regular basis. The hydrograph for this well (Figure 10) indicates an overall decline of about 10 ft. from the spring of 1979 to the spring of 1988. The following spring the artesian head had dropped another 8 ft. Since use of thermal water in this area is predominantly for irrigation, the abrupt decline in head during this time probably reflects increased use during 1987-88 drought.

Southwest of Rogerson

Three thermal wells have been drilled in the area southwest of Rogerson since the early 1980's. Driller's logs indicate that the wells are entirely completed in the Idavada Volcanics. Well depths range from 900 to 2525 ft. Based on a review of water rights in the area, current annual discharge is estimated at 1600 acre-ft. The highest water temperature recorded in the area is 32.0 °C (89.6 °F).

Beginning in the summer of 1985, monthly measurements were made of the artesian head in well 14S-15E-14CBD1. The hydrograph for this well (Figure 10) shows a trend similar to well 13S-16E-12DAA1, located south of Nat-Soo-Pah spring. The abrupt declines in head that have occurred since summer of 1988 are probably the result of conditions related to the drought in combination with perhaps increased pumpage in other irrigation wells completed in the thermal system.

Overall Conclusions Regarding Artesian Head

Although the local potentiometric surface has declined dramatically since pre-development in some areas, namely the area north of Buhl and Twin Falls, it appears that the current withdrawals from the system do not exceed the amount of recharge entering it. This is demonstrated by the fact that once development had ceased to expand in these areas, artesian heads stabilized relatively rapidly, indicating a new quasi-equilibrium had occurred between recharge and discharge in the system.

Estimates of total annual recharge to the geothermal system were made by Lewis and Young (1989). Although they qualify their results, their maximum estimate for recharge of 16,000 acre-ft/yr for the entire system implies that considerably less water is going into the system than is leaving it. If this were so, the potentiometric surface would have continued to decline in areas of development. The observed water-level trends in wells throughout the study area do not support this, and rather suggest that total recharge to the system must be at least equal to the total discharge from it.

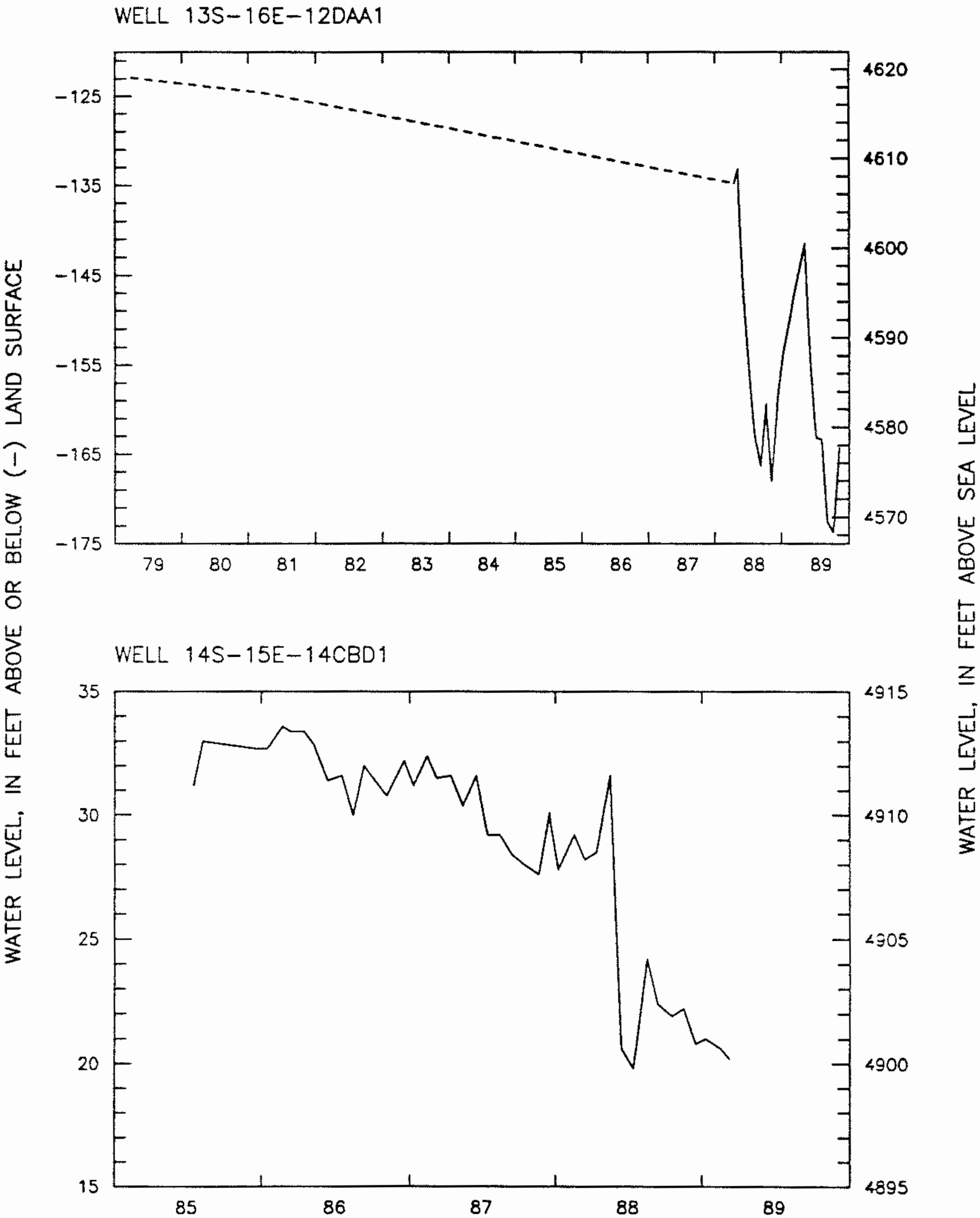


Figure 10. HYDROGRAPHS OF WELLS: 13S-16E-12DAA1 AND 14S-15E-14CBD1

GEOCHEMISTRY

Rock Chemistry

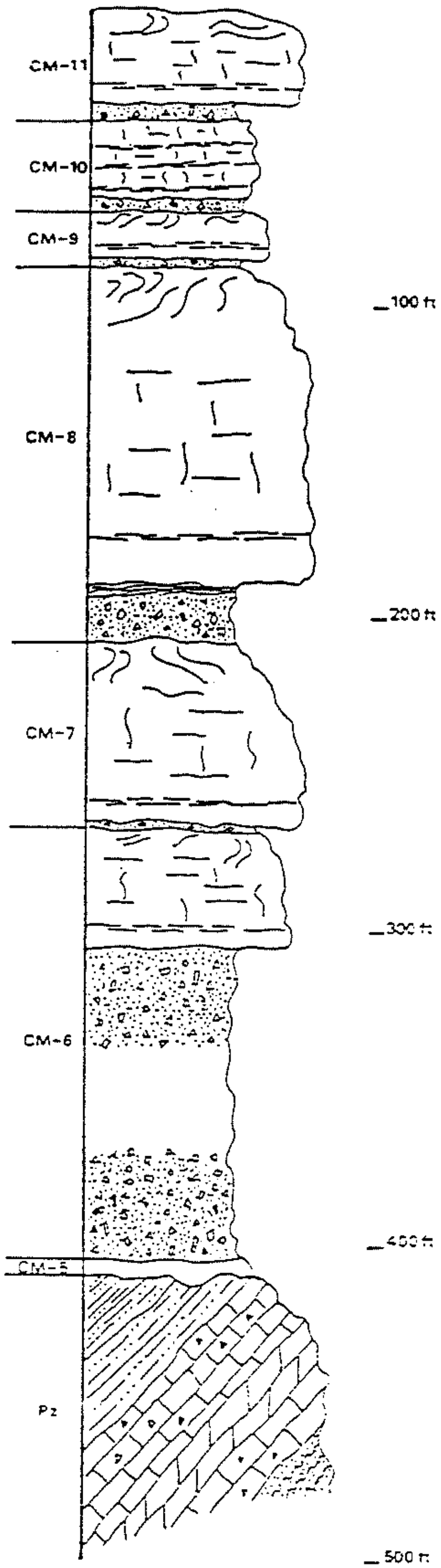
Thirty-five samples of the presumed host rocks for the geothermal system were collected for major element analysis within the immediate vicinity of the study area. Most of these samples were taken from selected units of the Idavada Volcanics that are exposed in the Cassia Mountains. A stratigraphic section showing the relative position of these units is included in Figure 11 (from Street and DeTar, 1987). Some other samples of silicic volcanics were also collected at Shoshone Falls and from drill cuttings of well 09S-17E-29ACD1. Two samples of the Paleozoic marine rocks were obtained near Nat-Soo-Pah Warm Spring.

Street and DeTar (1987) presented raw data for 19 samples of the silicic volcanics in their report. Table 3 includes some of their samples, in addition to previously unpublished data. Data shown in the table have been normalized and adjusted to volatile-free conditions. Where multiple samples of the same rock were analyzed, the data have been averaged and presented as a single analysis. For comparison, an average chemical composition of 64 samples from the Idavada Volcanics in southern Idaho (Wood and Low, 1988), has been included in the table.

Based on the results from the whole-rock chemistry the following conclusions were drawn. The silicic volcanics are composed of the following major chemical constituents (in order of decreasing concentration): SiO_2, Al_2O_3, Fe_2O_3, KO, and Na_2O. The prevalence of these constituents is expected, since the alumina-silicate minerals that make up these type of rocks consist almost entirely of these elements. Samples of the Paleozoic rocks indicate the major constituents (in order of decreasing concentration) are CaO, MgO, and SiO_2. These constituents occur in the minerals calcite, dolomite, and quartz, which are the primary minerals that compose these sedimentary rocks.

Water Chemistry

Several water samples have been collected as part of various studies that were conducted in the area. Lewis and Young's (1982) study of the Banbury Hot Springs area included chemical analyses of water from 21 wells and 2 springs. Their later study (1989), encompassed all of the current study area and presented results from 31 wells and 3 springs. Additional samples have been collected recently from 14 wells and 1 spring in and immediately outside the study area (see Table 4). Six of these samples were collected from sites that were previously sampled. Based upon our review of repeated observations shown in Table 4, it appears thatcontinued development of the thermal resource in these areas has had little, if any, effect on the water chemistry.



(Acquired from Street and DeTar, 1987)

CM-5 to CM-11: Units of the Idavada Volcanics exposed in the Cassia Mountains
Pz: Paleozoic marine sedimentary rocks

Figure 11. GENERALIZED STRATIGRAPHIC SECTION FOR THE CASSIA MOUNTAINS

Table 3. Chemical analyses of rocks from the Cassia Mountains and adjacent areas

(Analyses are in weight percent oxide)

Unit	Location[1]	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
IV[2]	--	71.27	0.47	12.42	0.48	0.05	0.36	1.36	2.83	5.26	0.09
WC[3]	09S-17E-29ACD1	74.90	0.36	12.42	3.01	0.05	0.18	0.64	3.43	4.94	0.06
SF[4]	09S-18E-31CAC	70.39	0.68	13.50	4.58	0.07	0.71	1.79	3.47	4.63	0.18
SF	09S-18E-31CAC	69.70	0.70	13.69	4.76	0.07	0.68	2.01	3.22	5.01	0.16
CM[5]-11	12S-18E-03AAD	74.01	0.47	12.43	3.65	0.05	0.20	1.02	2.89	5.19	0.10
CM-10	12S-18E-03ADA	73.46	0.49	12.57	4.00	0.06	0.26	1.17	2.68	5.19	0.12
CM-9	12S-18E-02CB	72.64	0.62	12.81	4.49	0.04	0.25	1.17	3.20	4.65	0.13
CM-8	12S-18E-03ADA	74.70	0.51	12.63	3.07	0.03	0.18	0.71	2.11	5.96	0.11
CM-8	12S-18E-03	75.71	0.32	12.11	2.47	0.04	0.13	0.60	2.80	5.76	0.06
CM-8	12S-18E-03ADA	71.79	0.65	12.90	4.68	0.07	0.50	1.70	3.24	4.32	0.14
CM-8	12S-18E-03	75.96	0.32	12.05	2.53	0.02	0.08	0.42	3.23	5.31	0.08
CM-8	12S-18E-02	72.11	0.66	12.81	4.64	0.06	0.39	1.52	3.14	4.38	0.29
CM-8	12S-18E-03	76.05	0.29	12.27	2.30	0.02	0.07	0.28	3.17	5.51	0.05
CM-7	12S-17E-33	68.75	0.74	13.13	5.08	0.06	0.62	2.30	2.97	4.85	0.14
CM-7	13S-17E-17CCA 12S-17E-33ACC	68.95	0.80	13.52	5.40	0.07	0.74	2.38	2.98	4.97	0.20
CM-6	13S-17E-17	69.28	0.61	12.82	4.24	0.06	0.45	2.06	2.98	4.87	0.12
CM-5	13S-17E-17CDB	74.06	0.44	12.38	3.68	0.04	0.21	0.90	2.51	5.70	0.08
PZ[6]	13S-17E-06ADD	12.29	0.02	0.54	0.23	0.09	35.73	50.82	0.05	0.17	0.06

[1] Location format identical to well- and spring-numbering system
[2] Idavada Volcanics, undifferentiated - average of 64 samples (taken from USGS Prof. Paper 1408-D, 1988)
[3] Well cuttings of Idavada Volcanics, undifferentiated
[4] Shoshone Falls Rhyolite
[5] Stratigraphic units of the Idavada Volcanics that are exposed in the Cassia Mountains (see Figure 11)
[6] Paleozoic marine sedimentary rocks

Table 4. Chemical analyses of water from selected wells and springs

(All constituents reported in mg/L, unless otherwise noted)

Well or spring number	Sample date	Specific conductance (µmhos/cm)	pH	Water temperature (°C.)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)
08S-14E-30ACD3	04/13/88	649	9.1	67.0	0.89	0.05	130.0	1.4	67.0	52.0
	12/07/88	--	--	67.5	0.94	<0.01	140.0	1.0	--	--
30DBA1	04/25/79	646	9.5	71.5	1.5	0.1	140.0	1.5	56.0	55.0
	04/13/88	640	9.1	66.0	0.91	0.04	140.0	1.4	63.0	51.0
	12/07/88	--	--	69.5	1.0	0.02	140.0	1.0	--	--
33CCA1	03/15/79	441	9.4	44.5	3.3	<0.1	100.0	1.8	83.0	38.0
	04/13/88	471	9.2	45.0	1.2	0.06	100.0	2.2	84.0	40.0
09S-14E-09ADC1	03/15/79	307	8.6	31.5	7.5	0.3	63.0	2.8	120.0	7.0
	04/13/88	323	8.7	32.0	6.9	0.32	62.0	3.3	120.0	5.5
	12/07/88	--	--	31.0	7.0	0.32	61.0	2.3	--	--
14BDB1	02/11/81	358	7.8	32.5	18.0	2.2	54.0	6.0	150.0	0.0
	12/07/88	--	--	33.0	19.0	2.4	51.0	6.0	--	--
09S-15E-12CCA1	06/23/81	427	9.3	44.0	1.5	0.1	96.0	1.5	78.0	38.0
	04/12/88	463	9.2	50.0	1.1	0.1	100.0	1.3	91.0	44.0
13BBD1	12/07/88	--	--	46.0	1.1	0.03	100.0	0.9	--	--
10S-16E-08CAB1	07/14/87	308	8.6	27.0	5.1	0.17	61.0	4.3	130.0	4.0
10S-17E-04CDA1	02/20/79	358	8.6	37.0	4.8	0.5	75.0	2.7	120.0	5.0
	02/09/81	360	8.5	37.0	4.3	0.2	78.0	2.3	120.0	5.0
	04/13/88	375	8.7	37.5	4.5	0.25	77.0	3.2	116.0	6.5
12S-17E-31BAB2	06/26/87	465	7.4	35.5	31.0	14.0	42.0	12.0	270.0	0.0
12S-18E-01BBA1	03/16/89	195	7.5	38.0	18.0	2.0	18.0	6.2	--	--
24BBD1	05/04/89	171	7.5	25.5	17.0	2.8	13.0	4.8	--	--
36BBA1	03/14/89	150	7.4	25.0	15.0	2.2	11.0	5.1	--	--
13S-15E-01DAD1	07/30/86	401	7.9	35.5	9.4	0.42	82.0	3.5	200.0	0.0
15S-14E-19CDD1S	05/23/89	29	6.0	7.0	1.5	0.25	2.5	3.9	--	--

Table 4. Chemical analyses of water from selected wells and springs -- Continued

(All constituents reported in mg/L, unless otherwise noted)

Well or spring number	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Silica (SiO_2)	Dissolved solids (calculated)	Nitrite plus nitrate as N (NO_2+NO_3)	Phosphorus, total as P	Arsenic (As) (µg/L)	Boron (B) (µg/L)	Lithium (Li) (µg/L)
08S-14E-30ACD3	32.0	49.0	27.0	85.0	--	<0.10	<0.01	60.0	460.0	51.0
	30.0	52.0	25.0	86.0	--	0.12	<0.01	49.0	440.0	51.0
30DBA1	33.0	51.0	27.0	82.0	402.0	<0.01	0.01	42.0	510.0	60.0
	34.0	50.0	28.0	86.0	--	<0.10	<0.01	63.0	470.0	51.0
	29.0	52.0	25.0	86.0	--	<0.10	<0.01	63.0	440.0	49.0
33CCA1	27.0	22.0	12.0	88.0	321.0	0.02	0.01	29.0	230.0	40.0
	32.0	22.0	14.0	91.0	--	<0.10	--	42.0	240.0	31.0
09S-14E-09ADC1	26.0	11.0	3.2	51.0	231.0	0.01	<0.01	23.0	120.0	50.0
	28.0	13.0	3.20	53.0	--	<0.10	<0.01	46.0	100.0	51.0
	25.0	12.0	2.70	53.0	--	<0.10	<0.01	24.0	90.0	51.0
14BDB1	27.0	13.0	2.5	71.0	268.0	0.50	--	17.0	90.0	60.0
	24.0	13.0	2.40	70.0	--	0.57	<0.01	10.0	100.0	51.0
09S-15E-12CCA1	24.0	14.0	16.0	75.0	304.0	0.13	--	56.0	200.0	30.0
	19.0	12.0	20.0	84.0	--	<0.10	<0.01	130.0	200.0	30.0
13BBD1	19.0	10.0	17.0	83.0	--	<0.10	<0.01	43.0	180.0	32.0
10S-16E-08CAB1	16.0	11.0	3.60	77.0	250.0	0.57	<0.01	--	--	--
10S-17E-04CDA1	20.0	12.0	12.0	56.0	248.0	0.42	--	17.0	180.0	<4.0
	22.0	14.0	11.0	59.0	255.0	0.47	--	16.0	180.0	10.0
	29.0	18.0	11.0	58.0	--	0.64	<0.01	15.0	150.0	9.0
12S-17E-31BAB2	18.0	5.2	1.9	19.0	--	<0.10	<0.01	--	--	--
12S-18E-01BBA1	6.8	7.8	0.50	67.0	--	0.70	<0.10	1.0	20.0	17.0
24BBD1	5.0	6.5	0.50	61.0	--	0.54	0.02	<1.0	10.0	15.0
36BBA1	4.7	6.0	0.40	67.0	--	0.63	0.02	<1.0	20.0	11.0
13S-15E-01DAD1	28.0	7.6	4.8	54.0	--	<0.10	0.01	--	--	--
15S-14E-19CDD1S	<1.0	0.20	0.10	48.0	--	0.20	0.02	<1.0	<10.0	<4.0

All of the above mentioned samples were analyzed for the following constituents: common ions (including silica) and the minor elements -- boron, lithium, and arsenic. Some of the samples were analyzed for phosphorus and mercury.

Major Constituents

Based on the rock and water chemistry data, the following observations regarding the water chemistry of the geothermal system have been made. Water from cold springs in the Cassia Mountains to the south of the study area (the presumed recharge area) is a calcium bicarbonate type. Samples of thermal water obtained from the Paleozoic rocks east of Hollister indicate a similar water type, although the concentrations of the various constituents is much greater. The calcium bicarbonate chemistry of these waters is not surprising since Paleozoic rocks are exposed and are presumably the host rock in these areas.

The calcium bicarbonate chemistry of the thermal water from wells completed in the silicic volcanics in this southern part of the study area is similar to the chemistry of the water from the Paleozoic rocks. Concentrations of the major constituents of these samples were less than the Paleozoic water samples, except for silica which was significantly greater. Silica concentrations were similar to other thermal waters from the silicic volcanics that were sampled in the north portion of the study area. Apparently, the residence time of the thermal water in this area is not long enough to allow it to equilibrate to the new host rock conditions and lose its Paleozoic signature.

Wells and springs that were sampled in the northern portion of the study area, all produce thermal water from the silicic volcanics. The chemistry of these waters is a sodium bicarbonate type. Temperature seems to strongly control the solute concentrations in the water. As water temperature increases, so does the concentrations of most of the chemical constituents, including sodium, silica, and fluoride, with the exception of calcium, where the opposite occurs. In general, chemical reactions, such as cation exchange reactions between calcium and sodium, increase with higher temperatures (Hem, 1985).

Minor Constituents

Boron concentrations in the wells and springs sampled range from less than 10 to as much as 510 micrograms per liter ($\mu g/L$). A common constituent of volcanic gases, boron is common in thermal waters. Some plants are extremely sensitive to boron, whereas others are relatively tolerant. Sensitive crops are those unable to tolerate concentrations above 124 $\mu g/L$., semitolerant crops are those able to tolerate concentrations from about 67 to 250 $\mu g/L$. and tolerant crops are those capable of tolerating boron concentrations from 100 - 375 µg/L. (Hem, 1985, p.216). Using these criteria, it's apparent that the boron concentration of much of the thermal water sampled is unsuitable for most plants in the Twin Falls study area. The U.S. Environmental Protection Agency; however, in their publication "Quality Criteria for Water 1986", state that an upper limit of 750 µg/L "is thought to protect sensitive crops during long-term irrigation."

Lithium was found in concentrations ranging from less than 4 to 80 µg/L in wells and springs sampled in the study area. Lithium is similar in effect to boron, and can be quite toxic to plants. According to Bradford (1963), citrus trees may be damaged by irrigation water containing 60 to 100 µg/L of lithium. It is not known what potentially toxic effect lithium in concentrations of 9 to 51 µg/L might have on crops commonly grown in the study area. If in the form of LiCl, it has been reported that "dilute concentrations" are harmful to the eggs of various aquatic organisms. Much larger concentrations, in the range of 1950 and 3770 mg/L were shown to kill fresh-water fish in about one day.

Arsenic in the wells and springs sampled ranged from less than 1 to as high as 130 µg/L. Like boron, arsenic is found in volcanic gases and is a common constituent in thermal water. An upper concentration limit of 50 µg/L was given in the 1976 drinking water standards (USEPA, 1976) for humans. McKee and Wolf (1963) report that long-term use of an arsenic concentration of 210 µg/L was poisonous. An upper limit of 200 µg/L has been recommended for livestock (NAS-NAE, 1972). Based upon these criteria, it appears that arsenic in the thermal water is not a significant environmental hazard over the short term.

Stable Isotopes

Isotope data, including oxygen-16 (^{16}O), oxygen-18 (^{18}O), and deuterium (D) were collected by the USGS (Lewis and Young, 1989) as part of this study, and are reported in the reference given. Lewis and Young conclude that water within the silicic volcanics, based upon these data, is in the range of at least 8,000 to possibly 15,000 years old.

Recent results from carbon-14 and total helium data collected this past year indicate slightly different ages of the thermal water in the study area (R.L. Mariner, USGS, oral communication, 1990). These data indicate ages ranging from 5,000 to about 10,000 years old, with a general increase in age from south to north. In addition to these findings, the data also suggest a divergence in the principal directions of flow at the northern margin of the study area. Thermal water in the Twin Falls area appears to have a strong east-to-west component of flow to it, as opposed to the predominant north-south direction of flow in the remainder of the study area.

CONCEPTUAL MODEL

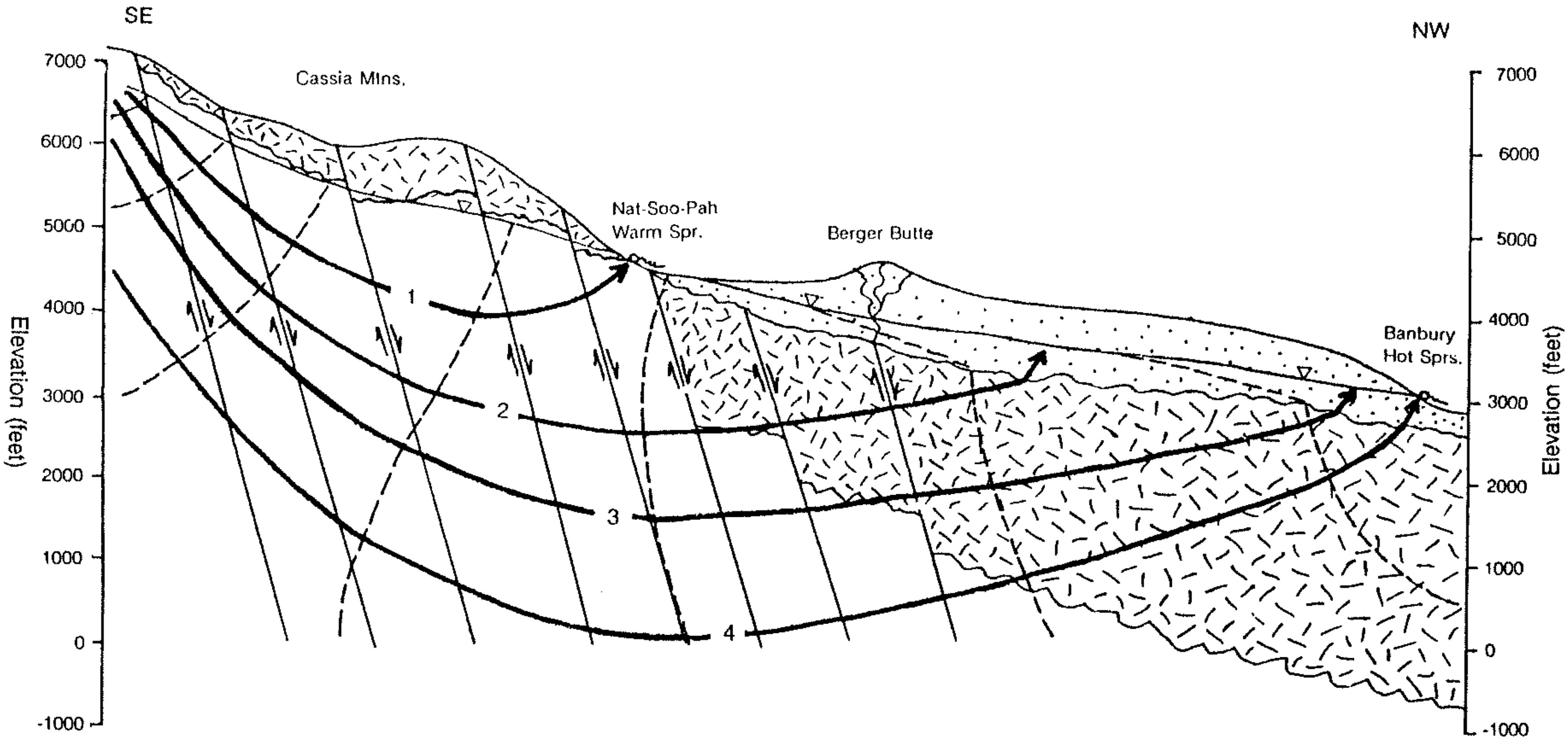
Past studies of the geothermal system (Street and DeTar, 1987; Lewis and Young, 1989) have proposed conceptual models that entail only the silicic volcanics as the host rocks for the system. Although thermal water has been encountered predominantly in the volcanics, it also occurs within the Paleozoic rocks east of Hollister and at springs to south of the study area. Paleozoic rocks are also at or near the land surface in the presumed recharge areas for the system. We propose one composite model for the entire geothermal system that attempts to explain the hydrothermal relationship between these two reservoir rocks. As with the other models, available geologic, hydrologic, and geochemical data were used to develop it.

A simplified hydrogeologic profile of the geothermal system is presented on Figure 12 to illustrate our concept. Although the profile is oriented along the Berger-Buhl Structure Zone, the ideas that are presented apply in general to other lines of projection. The geologic features shown on the profile may be over-simplified, however, they do generally reflect the data that has been acquired from field mapping and geophysics. The flow net that is superimposed on the profile is entirely conceptual and is based largely on locations of the presumed recharge and discharge areas of the system. The equipotential lines (shown with dashed lines on the profile) represent lines of equal hydraulic head. The four flow lines that are depicted represent general flow paths in the system. The actual flow regime is undoubtedly more complicated than what is shown, however, the basic concepts that are proposed may still apply.

In general, most water that recharges the geothermal system originates as meteoric water in the mountainous terrain (the Cassia Mountains) to the south and southeast of the study area. After some near-surface evaporation, it enters extensive fracture networks in the Paleozoic rocks and overlying silicic volcanics. As the water descends, it becomes progressively heated (and less dense) from the regionally high temperature gradient. Depending upon the extent of individual fracture networks and associated head drive, various depths of circulation and lengths of flow paths occur.

The shortest flow paths within the geothermal system, as depicted by flow line 1, occur entirely within the Paleozoic rocks. The calcium bicarbonate chemistry of the water at its point of discharge near Nat-Soo-Pah spring reflects this. Residence time of the thermal water in this area is about 5000 years.

As the flow paths become longer, waters encounter the silicic volcanics during their movement. The chemistry of the thermal water gradually re-equilibrates to the new host rock conditions and



HORIZONTAL SCALE 1: 365,000

VERTICAL EXAGGERATION X15

EXPLANTION

GEOLOGIC FEATURES

- Quaternary-Tertiary Basalts
- Tertiary Idavada Volcanics
- Paleozoic Sedimentary Rocks

HYDROLOGIC FEATURES

- ▽ Potentiometric Surface
- Equipotential Line (contour interval = 500 ft)
- Flow Line

Figure 12. CONCEPTUAL HYDROGEOLOGIC PROFILE OF GEOTHERMAL SYSTEM

loses some of its Paleozoic signature as exposure time increases. Thermal water in the area southwest of Rogerson represents this transient condition of the water chemistry. Due to the elevation of the land surface and thickness of the semi-confining layers, thermal water along these flow paths discharges directly into the cold-water system in the overlying basalts, as shown by flow line 2.

At greater depths of circulation, the temperature of the water gradually increases and so does its ability to dissolve minerals along its flow paths. Flow lines 3 and 4 illustrate this concept and the reason for the variation of solute concentrations in thermal water north of Buhl. Residence time of the water in this area is about 10,000 years.

It appears that natural discharge from the geothermal system occurs primarily through upward leakage to the overlying cold-water system. The Banbury Hot Springs area is probably the location of final discharge from the geothermal system. However, some thermal water may remain in the system and leak upward into the immense eastern Snake River Plain aquifer system. This cold-water system eventually discharges in the Thousand Springs area of the Snake River.

Since the completion of wells in the regional geothermal system, the flow regime of the system has been dramatically altered. Based on observed water-level trends, it appears that in areas where development has lowered the potentiometric surface, the amount of upward leakage that naturally took place has been reduced. In other words, the effects of development on the natural flow regime have been to redistribute and concentrate the water leaving the system to areas of extensive development.

Long-term variations in recharge probably have caused significant changes to the flow regime of the geothermal system. Water that is leaving the system now originated during a period when the climate was cooler and wetter (Lewis and Young, 1989). Climatic conditions since this time have become progressively warmer and dryer, and as a result, the amount of water going into the system now is undoubtedly less than it was 5,000-10,000 years ago. However, since the onset of development, annual variations in recharge have probably had little effect on the current flow regime.

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